Reassessment of Lower Palaeozoic geology west of the Catombal Range, Wellington region, central New South Wales

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New palaeontological discoveries and revised mapping of Lower Palaeozoic sedimentary rocks located west of the Catombal Range, between Wellington and Yeoval in central New South Wales, underpins a new model for the Ordovician and Silurian geological history of this region. West of the abandoned Gunners Dam gold mine, large blocks of deep-water siltstones, spiculite, and laminated chert contain Late Ordovician graptolites, including *Dicellograptus* and *Climacograptus* (associated with the dendroid *Dendrograptus*). Along strike to the north near Arthurville, west of Wellington, lensoidal outcrops of sandstone, conglomerate and limestone (previously assigned to the Oakdale Formation) contain a new brachiopod genus and species, described here as *Narrawaella wellingtonense*, that is associated with conodonts and lingulate brachiopods of Late Ordovician (Katian) age. We interpret all these Upper Ordovician rocks as allochthonous, having been redeposited into Silurian sediments of the Cowra Trough. Similar occurrences of allochthonous Upper Ordovician limestones at Eurimbla and Cumnock to the south, and comparable deposits previously recognised in the Hill End Trough further to the east, suggest this model is widely applicable to areas peripheral to the Macquarie Arc in central New South Wales.

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KEYWORDS: allochthonous blocks, brachiopods, graptolites, Silurian, stratigraphy, Upper Ordovician

INTRODUCTION

Ordovician rocks in the eastern Lachlan Orogen of south-eastern Australia include continent-derived, quartz-rich turbidite sequences (VandenBerg and Stewart 1992; Glen et al. 2009) and volcanic-volcaniclastic sequences with associated shelfal limestones and slope to basinal sediments (Fig. 1A). The latter are collectively attributed to the Macquarie Arc, an intra-oceanic arc system (Glen et al. 1998; Crawford et al. 2007). These Ordovician strata are now largely separated by Silurian and Devonian trough deposits (Glen 2005). The arc sequences are fragmented, with the westerly Junee-Narromine Volcanic Belt separated from the central Molong Volcanic Belt by the Silurian-Devonian Cowra Trough.

Due to their structural dismemberment, relationships between the belts of the former island arc are not well-preserved, particularly in areas of isolated exposures. The most recent geological map of the Wellington region (Morgan et al. 1999a) depicts two belts of Ordovician strata, bounded on their eastern sides by major north-south faults (Cudal Fault and Manildra Fault) extending between Ponto in the north and Cumnock in the south. These rocks were mapped as Oakdale Formation (in the Arthurville area to the north, and between Smokey Camp and Bournewood localities further south), Sourges Shale in the vicinity of Cumnock, northwest of Molong, and the regionally extensive Kabadah Formation (Fig. 1B). Outcrops in these belts include large blocks and lenses of deep water chert and spiculitic siltstone in the vicinity of the abandoned Gunners Dam mine, and shallow water limestone, conglomerate and sandstone on Narrawa property, west of Arthurville. Additional fossil discoveries confirm the Late Ordovician age of these rocks which recent field mapping suggests have

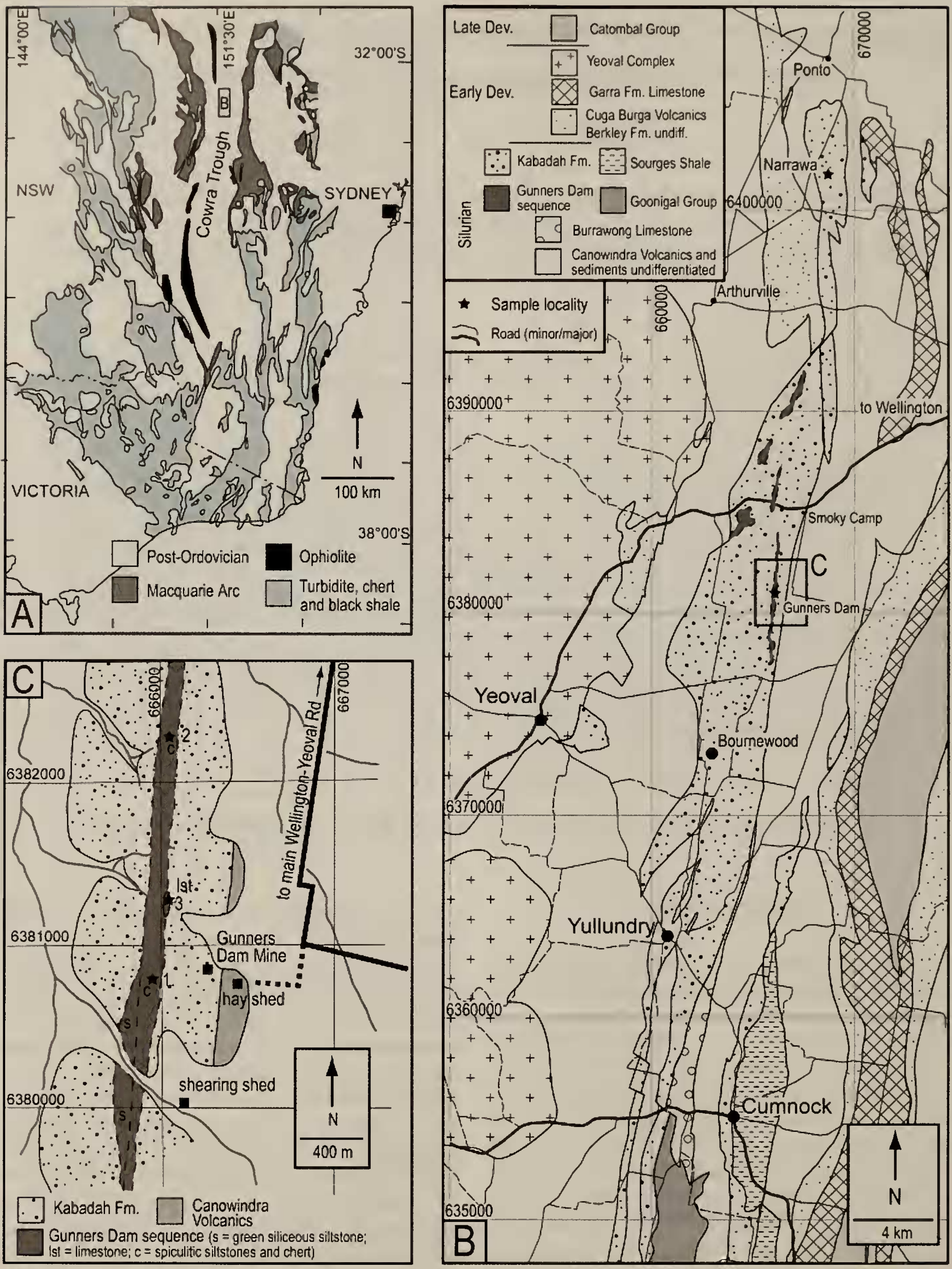

Figure 1. A. Locality map showing distribution of Ordovician rocks in eastern New South Wales and northeastern Victoria. B. Revised geological map of the area west of the Catombal Range near Wellington in central New South Wales. C. Detailed geological map of the area immediately west and north of the abandoned Gunners Dam mine, showing distribution of allochthonous blocks of Upper Ordovician rocks that are the subject of this paper.

all been redeposited into younger sediments, leading to a reassessment of structural and stratigraphic relationships in the region.

STRATIGRAPHIC RELATIONSHIPS ON NARRAWA

A prominent belt of Upper Devonian rocks forming the Catombal Range, extending west and southwest of Wellington, separates two areas in the central west of NSW that have previously been mapped as Oakdale Formation. Southeast of Wellington near Dripstone, in its type area in the Oakdale Anticline, the Oakdale Formation consists of volcaniclastic sandstone, siltstone and occasional allochthonous limestone lenses and clasts that range in age from late Darriwilian (Da3: Zhen and Percival 2004) to Eastonian (Morgan et al. 1999c).

Rocks assigned to the Oakdale Formation on Narrawa property, adjacent to the Arthurville Road west of Wellington (Fig. 1B), occur in paddocks centred on GR 669255 6402762 (GDA), 1.5 km northeast of Narrawa homestead. These outcrops include metre-scale blocks of moderate to coarse-grained, thinly to moderately thick-bedded quartz sandstones rich in brachiopods, overlain by discontinuous exposures of maroon siltstones and fine-grained sandstones, in which trilobite remains are abundant. Contacts between the various blocks and lenses are covered by soil, so that stratigraphic continuity and thickness cannot be established. Where dips can be measured, all beds are east-dipping at about 10–20 degrees. In stratigraphically higher beds, clasts of limestone become progressively more common, forming allochthonous limestone breccia that includes blocks containing halysitid corals (presumably of shallow water origin), intermixed with clasts derived from a deeper water depositional setting (indicated by their microbrachiopod fauna). Age of these limestones is late Eastonian to early Bolindian (i.e. mid to late Katian of international usage), based on conodonts and microbrachiopods (Percival et al. 1999).

Biostratigraphy

Percival et al. (1999) published a preliminary faunal list from exposures then referred to Oakdale Formation on Narrawa and discussed the age implications. Updated determinations are as follows:

allochthonous limestone blocks (NSWGS conodont sample C1491)

Conodonta

Belodina confluens
Drepanoistodus sp.
Panderodus gracilis
Periodon grandis
Protopanderodus sp. cf. *P. liripipus*
Yaoxianognathus? sp.

Brachiopoda

Atansoria sp. nov.
Nushbiella sp. nov.
Paterula malongulliensis Percival, 1978

Cnidaria

Halysitid coral cf. *Halysites praecedens* Webby and Semeniuk, 1969

underlying sandstone blocks at GR 669255 6402762 (GDA)

Brachiopoda

Narrawaella wellingtonense gen. et sp. nov.

Trilobita

indet. encrinurid
indet. dikelocephalinid

Although several of the identifications given in Percival et al. (1999) have been revised, the age of the limestone clasts at Narrawa is still regarded as most likely late Eastonian (Ea3-4), or late Katian, based on the occurrence of conodonts and brachiopods identical at species level with those in the Malongulli Formation in the Cliefden Caves area (Trotter and Webby 1995; Percival et al. in review), and in the Downderry Limestone Member of the Ballingoole Limestone and overlying basal beds of the Malachis Hill Formation at Bowan Park (Zhen et al. 1999). All these units contain elements of the same lingulate brachiopod assemblage (particularly the new species of *Atansoria* and *Nushbiella*, described by Percival et al. in review) as recognised in allochthonous limestone blocks at Narrawa. However, the new brachiopod *Narrawaella wellingtonense* and associated trilobites found in the underlying sandstones and siltstones are unknown in Ordovician rocks of eastern Australia; their assumed late Eastonian age is based on proximity to the stratigraphically overlying limestone blocks.

STRATIGRAPHIC RELATIONSHIPS AROUND GUNNERS DAM MINE

The abandoned Gunners Dam gold mine (situated approximately 25 km southwest of Wellington: Fig. 1B, C) was previously interpreted by Warren (in Morgan 1997) and Morgan et al. (1999c) to be situated within the Oakdale Formation. These authors described andesitic breccia and volcaniclastic cobble conglomerate in the vicinity of the mine, relating these

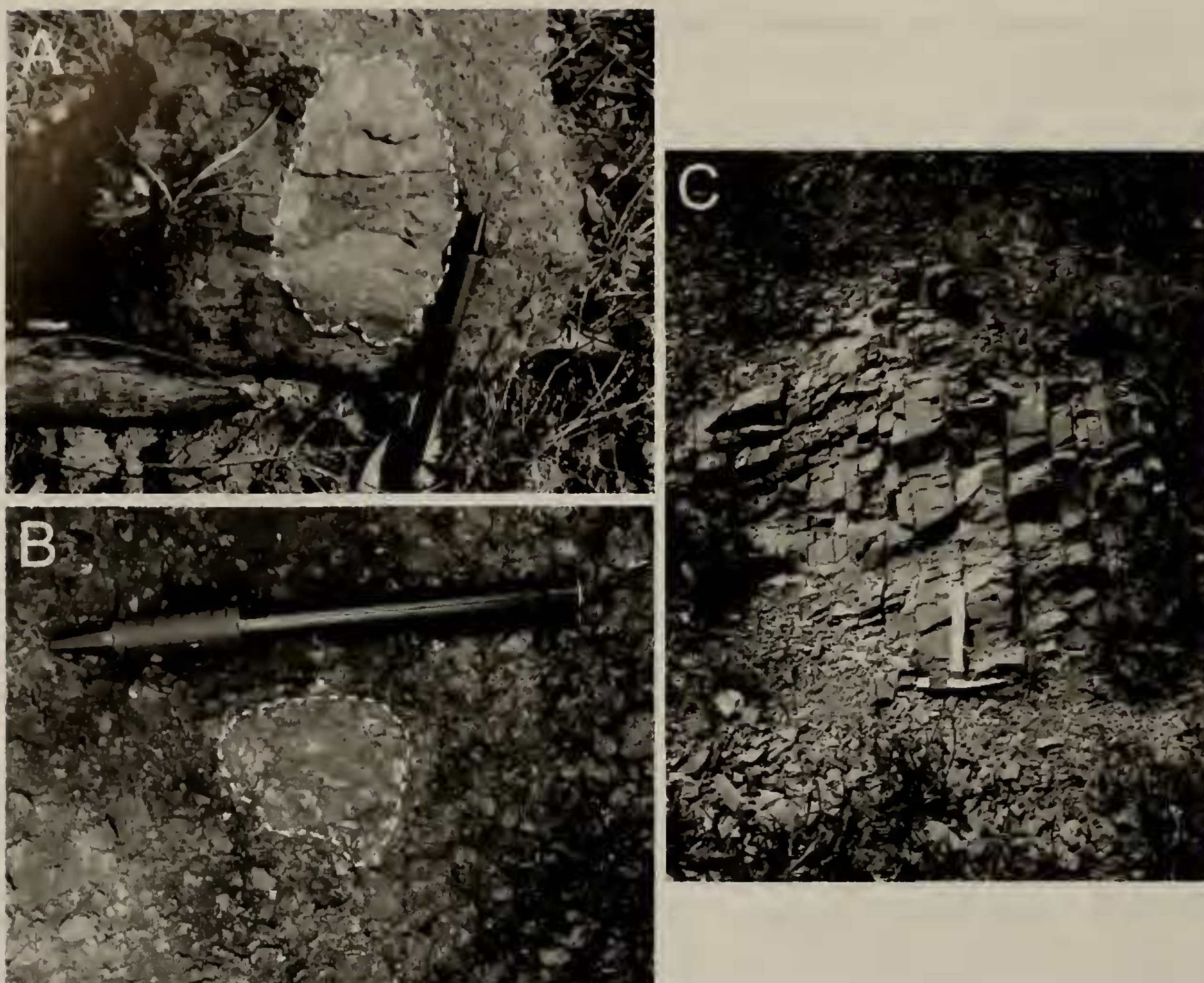

Figure 2. Field photographs of representative lithologies. A. clasts of plagioclase-phyric andesitic volcanic rock within a locally monomictic conglomerate. This outcrop, about 20 m east of the allochthonous limestone block described herein (sample locality 3 in Figure 1C), was originally attributed to the Oakdale Formation but is here regarded as part of the Lower Silurian Kabadah Formation. These clasts are superficially similar to the Devonian Cuga Burga Volcanics. B. Detailed view of clast in A. C. bedded siliceous siltstones forming a clast within the Gunners Dam sequence; outcrop is approximately 50 m west of the limestone block (locality 3).

rocks to a nearby volcanic centre. Gold mineralisation at Gunners Dam has been briefly discussed by Warren (in Morgan 1997) as occurring in quartz reefs emplaced along fault zones. Relatively undeformed sedimentary rocks forming the ridge to the west of the mine workings, in which Late Ordovician graptolites and other fauna (documented herein) occur, were originally assigned to the Kabadah Formation, most recently by Morgan et al. (1999a, b), who thereby inferred an extended Late Ordovician to Early Silurian age for that unit. Percival and Glen (2007, p.152-153) briefly compared the lithology and fossil content of the Kabadah Formation with the exposures in the vicinity of Gunners Dam and on the adjoining property Pine Not, concluding that a separate stratigraphic name was warranted for the Upper Ordovician deep-water strata that they informally termed the Gunners Dam beds. However, as is now apparent from the latest detailed mapping of the area presented herein, these exposures are discontinuous and likely represent large-scale (up to km-long) allochthonous olistoliths rather than either an in-situ formation, or tectonically-emplaced slivers.

In the immediate vicinity of the Gunners Dam mine, rocks consistently dip moderately to steeply to the west (mean ca. 65 degrees). The sequence is here reinterpreted to pass from crystal-rich dacites and sedimentary rocks of the Lower Silurian Canowindra Volcanics to the east, upwards through volcanic debris flows, conglomerate with chert and volcanic fragments, and mafic to intermediate autobreccia (Fig. 2A-B). These rocks are apparently overlain along the ridge to the west by deep-water spiculitic and graptolitic siltstones (Fig. 2C) associated with laminated cherts (laminations ca. 5-10 mm) yielding Late Ordovician fossils, discussed further below.

Still further west above this succession, along a north-south trend, lie mafic sandstones, grits and conglomerates (with chert, andesite and granite clasts) of the Lower Silurian Kabadah Formation. Small (ca. 1-2 cm) granite and volcanic clasts were observed in the vicinity of GR 665600 6381150 (GDA) on Pine Not property south of the main Wellington – Yeoval road (known as Renshaw-McGirr Way).

Although siltstone matrix separating blocks of chert within the mapped horizon could not be confirmed during this fieldwork, the Ordovician chert horizon was found to be discontinuous along strike – particularly in the vicinity of GR 665710 6376860 (GDA) where it gave way to green siliceous siltstones exposed in a quarry. These siltstones were also observed in the creek at GR 665750 6380250 (GDA) and perhaps correlate with the Lower Silurian Sourges Shale to the south near Cumnock.

Biostratigraphy

Rocks surrounding the abandoned mine workings are strongly cleaved and lack fossils, so their age is uncertain. Poorly preserved graptolites from overlying siltstones exposed in the ridge 200-300 m to the west of the mine site had been determined by A.H.M. VandenBerg (cited in Morgan et al. 1999b) to indicate a Late Ordovician age, though none could be identified to genus level. Associated cherty beds contained conodonts (also indeterminate) regarded by I. Stewart (cited in Morgan et al. 1999b) as no older than Darriwilian in age. Further intensive searching of these beds by R.A. Glen and I.G. Percival on field trips in 2002 and 2006 revealed additional graptolite fragments including an indeterminate orthograptid, although again this material was inconclusive in providing a definitive age.

Recent collecting at this locality (Fig. 1C, locality 1), and in siltstones apparently at a higher stratigraphic level in exposures to the north (locality 2) has yielded a graptolite fauna that includes several species confirming a Late Ordovician (late Katian: Eastonian 3 to Bolindian 2) age. The fauna includes the following:

Locality 1 GR 665950 6380820 (GDA): siltstones and interbedded cherts
Graptolithina (Fig. 3, 4, 5B-D, I)
Dendrograptus sp.
Dictyonema? sp.
Dicellograptus sp.
climacograptid indet.
Conodonta (Fig. 5E, F, H, J)
Belodina sp.
Paroistodus venustus?
Phragmodus? sp.
Scolecodonta indet. (Fig. 5G)
Porifera (Fig. 5A)
Sponge spicules

Locality 2 GR 666080 6382250 (GDA): siltstone (apparently higher in section)
Graptolithina (Fig. 4)
Climacograptus spp.

A solitary limestone block (ca. 15 m diameter), itself consisting of redeposited limestone clasts rich in echinoderm fragments, lies immediately east of the chert package within a creek at GR 666005 6381265 (GDA) (Fig. 1C). Although contacts with nearby outcrops (Fig. 2) were not exposed due to thick soil cover, and matrix siltstones again were not observed, based on regional dips this limestone block appears to lie directly above conglomerates (Fig. 2A-B) and underlies the cherts and graptolitic siltstones previously discussed (Fig. 2C). Acid-insoluble residue from the limestone block (locality 3) yielded the following microfauna:

Locality 3 GR 666005 6381265 (GDA):
allochthonous limestone

Conodonts	*Periodon* sp. (possibly *P. grandis*)
	Panderodus sp.
	Pseudooneotodus? sp.
	Yaoxianognathus? sp.
Brachiopods	*Paterula* sp
	indet. orbiculoidid
Bivalves	indet. fragments
Bryozoan	fragment
Indeterminate conical tubes	

Despite the paucity of conodont elements recovered from this sample, the assemblage is certainly of Late Ordovician, most likely Eastonian, age, and is therefore approximately contemporaneous with the ages obtained from other clasts investigated in this study. These fossiliferous Ordovician rocks are adjacent to debris-flows and conglomerates within siltstone matrix and probably represent large olistoliths several tens to hundreds of metres long, rather than having been emplaced as extremely thin thrust-imbricated slices. None of the fossils in these rocks are distorted, and no increases in strain were observed towards any contacts.

AGE OF THE KABADAH FORMATION AND AFFINITIES WITH CANOWINDRA VOLCANICS

The Kabadah Formation, as defined by Maggs (1963) from the vicinity of Cumnock, consists of

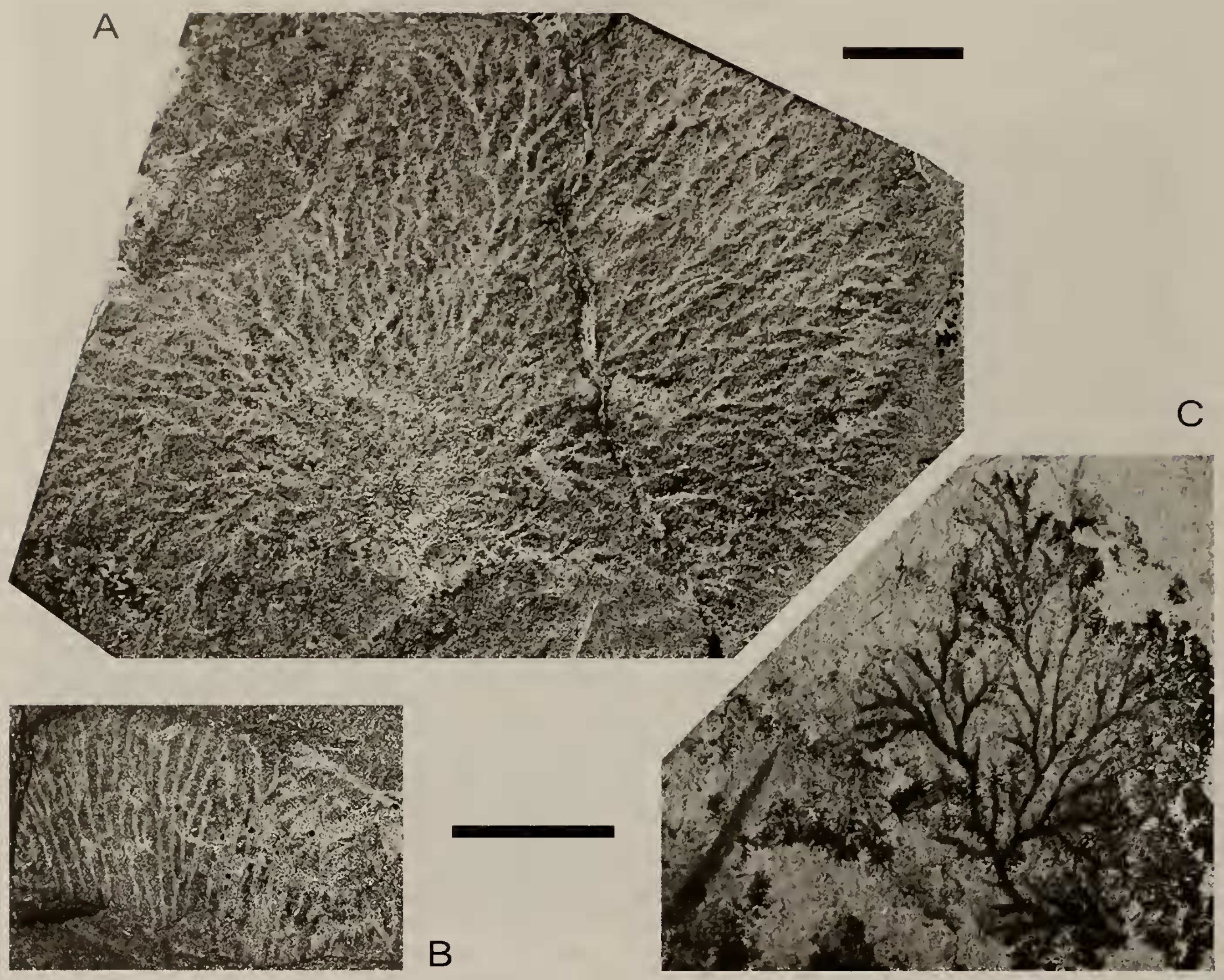

Figure 3. A. *Dendrograptus* sp., a near complete rhabdosome preserved in slight positive relief, MMF 45087. Scale bar represents 10 mm (magnification x1.5). B. *Dictyonema*? sp., fragment exhibiting parallel stipes and rare dissepiments (note that right-hand side of specimen is damaged with scratch-marks), MMF 45088. C. *Dendrograptus* sp. showing irregular widely-spaced dichotomous branching of stipes, MMF 45089; note specimen of *Climacograptus* sp. in lower left of photograph. Scale bar represents 10 mm (magnification of specimens B and C is x2). All specimens from ridge crest west of Gunners Dam mine at locality 1 (see Fig. 1 and text for details).

a series of matrix-supported, limestone-clast and angular polymictic conglomerates or debris flows within a cleaved and deformed siltstone-coarse shale matrix. Sherwin (1973) identified graptolites within the basal shale that indicated an age no older than early Llandoverian, prompting Bradley (*in* Pickett 1982) to include the Kabadah Formation in the Silurian Cudal Group.

Raymond and Pogson (1998), followed by Morgan et al. (1999b), mapped the spatial distribution of the Kabadah Formation by its high K-radiometric response that they attributed to arc-related detritus, and so included the formation in the Cabonne Group that otherwise consists of Late Ordovician volcaniclastic and volcanic rocks associated with the Macquarie intra-oceanic arc. The presence of Early Silurian fossils in the Kabadah Formation was used to support the extension of the age of the Cabonne Group across the Ordovician-Silurian boundary. However, as pointed out by Percival and Glen (2007), such a high-K radiometric response is not unique to Macquarie Arc-related rocks in the Lachlan Orogen, and merely reflects the presence of arc detritus subsequently redeposited into the Kabadah Formation. High K-radiometric responses are also typical of Early Devonian debris flow horizons elsewhere in the Lachlan Orogen and on closer inspection contrasts with a slightly higher U and Th response of the arc rocks.

Barron et al. (2007), after Barron and Warren (1998), reported ultramafic, arc-related and other

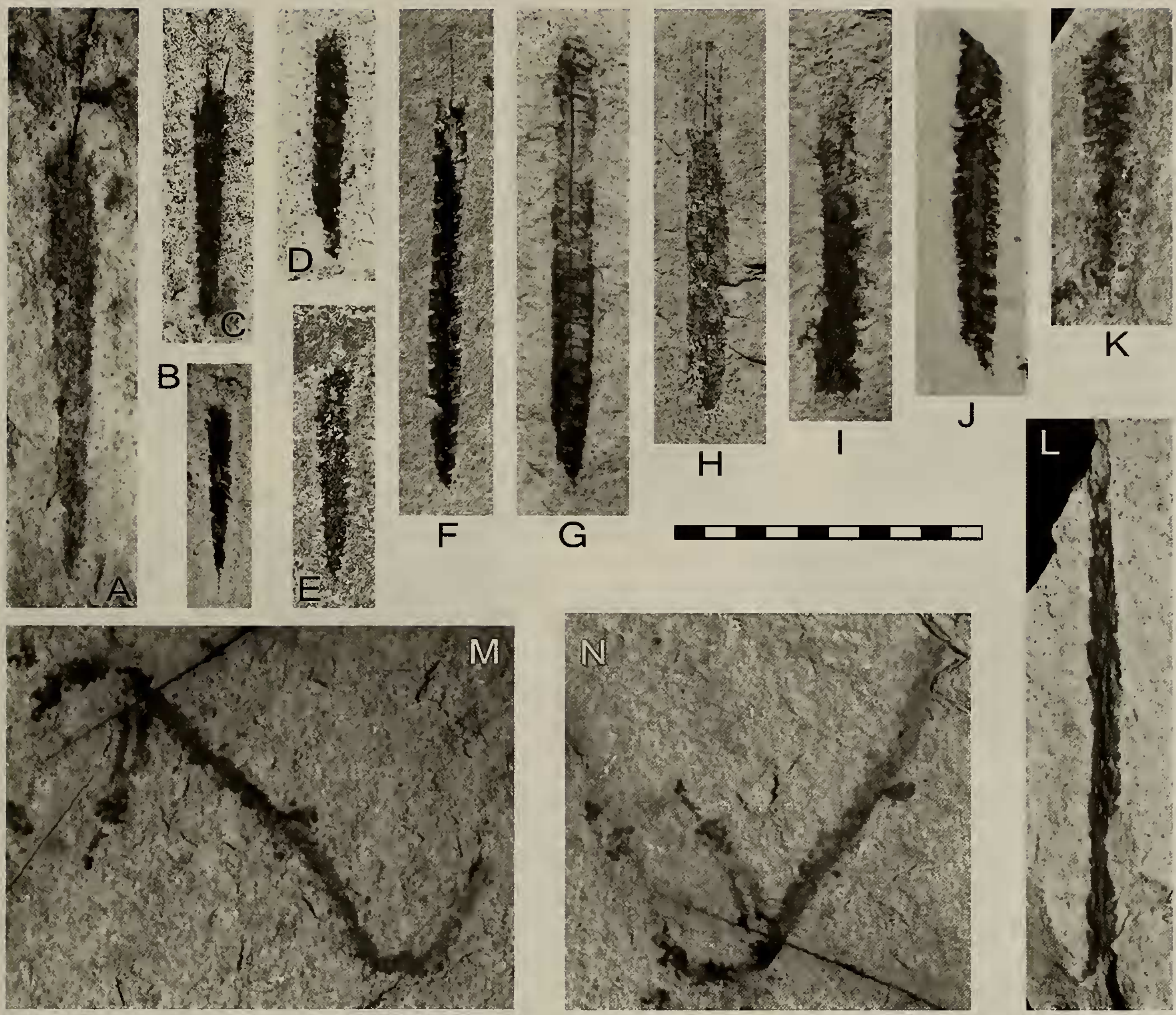

Figure 4. Graptolites from west (locality 1, specimens A, M and N) and northwest (locality 2, specimens B – L) of abandoned Gunners Dam mine (see text for details). A: climacograptid indet., MMF 45090; note that the nema-like artefact at the top of the specimen is a crack in the rock surface. B: *Climacograptus* sp., MMF 45091; note that the right-hand side of the proximal part of this specimen is broken obliquely to the stipe, giving an impression of a more sharply tapering outline than is in fact the case. C: *Climacograptus* sp., with a near-vertical rock fracture intersecting upper right side of specimen. MMF 45092. D: *Climacograptus* sp., MMF 45093. E: *Climacograptus* sp., MMF 45094. F: *Climacograptus* sp., MMF 45095. G: *Climacograptus* sp., MMF 45096. H: climacograptid indet., MMF 45097. I: indeterminate climacograptid lacking proximal half, MMF 45098. J: *Climacograptus* sp. in oblique scalariform view, MMF 45099. K. *Climacograptus* sp., MMF 45100. L. fragment of stipe of an indeterminate dicellograptid, MMF 45101. M: *Dicellograptus* cf. *D. minor,* MMF 45102a, in lower right of image; N: interpreted as a single stipe of an indeterminate dicellograptid, representing the counterpart (MMF 45102b) of the upper left side of M, that overlaps the specimen of *Dicellograptus* cf. *D. minor*. Scale bar represents 1 cm, with 1 mm increments; all specimens enlarged x4.

detritus within sandstones and conglomerates of the Kabadah Formation, including detrital chromite, pyroxene, volcanic quartz, garnet, lithic clasts of S-type cordierite + garnet-bearing dacitic volcanics, granite clasts (most likely related to the Cowra Granodiorite) and deformed sediments. Barron et al. (2007) argued that the Kabadah Formation was entirely restricted to the Early Silurian, and attributed the existence of the cordierite + garnet-bearing dacite clasts to an early unexposed phase of the Canowindra Volcanics.

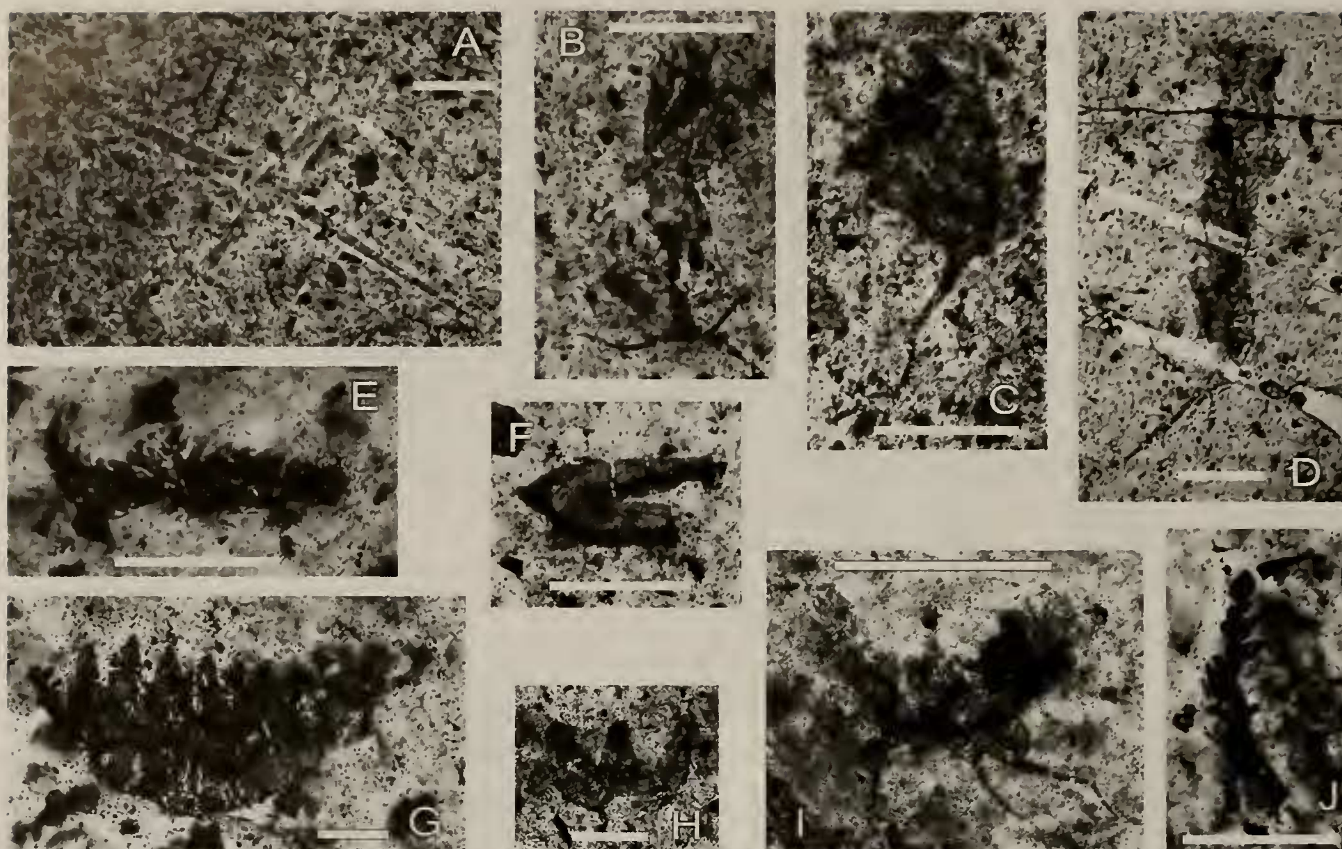

Figure 5. Fossils in thick-sections of chert from locality 1, west of abandoned Gunners Dam mine (see Fig. 1C and text for details). Scale bars represent 1 mm. A: sponge spicule, MMMC 4400. B – D, I: proximal ends of graptolites. B. indeterminate climacograptid with two basal spines, MMMC 4401. C: indeterminate orthograptid?, MMMC 4402. D: indeterminate climacograptid with two basal spines, overlain by two sponge spicules, MMMC 4403. I: indeterminate dicellograptid, MMMC 4404. E – F, H, J: conodonts. E: *Phragmodus*? sp., MMMC 4405. F: *Paroistodus venustus*?, MMMC 4406. H: indeterminate element, MMMC 4407. J: *Belodina* sp., MMMC 4408. G: indeterminate scolecodont MMMC 4409.

The Canowindra Volcanics elsewhere overlies the Gospel Oak Shale (Ryall 1966) which contains a graptolite fauna spanning the middle late Llandovery to earliest Wenlock interval, and is overlain disconformably by the Avoca Valley Shale (Bradley, in Pickett 1982) and Ghost Hill Formation (Ryall 1966), both of which contain the graptolite *Pristiograptus dubius* indicative of a broad Wenlock to Ludlow age (Krynen and Pogson 1998). The calculated weighted mean U-Pb zircon ages for the Canowindra Volcanics (432 ± 7Ma and 431.7 ± 3.1 Ma) are latest Llandovery (after Pogson 2009) or late Llandovery (mid Telychian, *M. turriculatus* to *M. crispus* graptolite zones, according to the Silurian timescale proposed by Sadler et al. 2009). The presence in the Kabadah Formation of lithic clasts with probable Canowindra Volcanics affinities confirms that the age of the Kabadah Formation most likely ranges from the Llandovery into the Wenlock, with the possibility that the upper part extends into the Late Silurian. Much more fieldwork and sampling is needed to accurately constrain the extent of both formations.

DISCUSSION

The lithological, depositional and biostratigraphic attributes of the rock successions in the Narrawa and Gunners Dam–Pine Not areas combine to support a re-evaluation of Upper Ordovician stratigraphy in the belt west of the Catombal Range. All these isolated outcrops of Ordovician fossiliferous rocks most likely (given their juxtaposition over such a small area) represent allochthonous blocks (here informally termed the Gunners Dam sequence – see Fig. 1C) redeposited into Silurian sediments of the Cowra Trough succession.

Sandstone and carbonate rocks at Narrawa are reinterpreted as an outer shelf facies equivalent of the deeper water Gunners Dam sequence. These lithologies are all late Eastonian to early Bolindian in age. Faunas within the limestone clasts at Narrawa are very similar to those of deep-water limestones found in the Malongulli Formation that overlies the Cliefden Caves Limestone Subgroup in the southern Molong Volcanic Belt of the Macquarie Arc. However, the tectonic setting of these areas is very different. The Gunners Dam – Narrawa area lies west of the Catombal Range, which is a belt of Upper Devonian rocks along the margin of the Cowra Trough, separating that area from the northern part of the Molong Volcanic Belt (east of the Catombal Range). Whereas allochthonous clasts in the Malongulli Formation were deposited penecontemporaneously into that formation, the allochthonous rocks of Late Ordovician age west of the Catombal Range were redeposited into Silurian rocks of the Cowra Trough. A comparable situation has been described from the Eurimbla area some 10 km to the south of the Gunners Dam area, where clasts of Late Ordovician limestone were redeposited in sediments forming the Late Silurian Barnby Hills Shale (Zhen et al. 2003).

Similarly, the status of several km-long limestone lenses of Late Ordovician age previously mapped as an unnamed member within the Sourges Shale in the vicinity of Cumnock (Percival et al. 1999: fig. 5) requires revision – the southernmost one is of early Eastonian (Ea1) age and of very shallow water aspect, whereas those to the north on a markedly different trend are significantly younger (Ea3) and contain a deeper water fauna. Recognition of these limestones as allochthonous blocks enclosed within sediments of known Llandovery age confirms that the Sourges Shale reverts to a Silurian formation within the Cudal Group, as foreshadowed by Morgan (1999).

Recognition of widespread allochthoneity of rocks formerly mapped as Ordovician in the region between Ponto in the north and Cumnock in the south, bounded to the east by the Catombal Range and to the west by the Yeoval Granite, removes the need to infer the Cudal and Manildra faults that previously were mapped between belts of Ordovician and Silurian strata. In-situ Ordovician strata appear to be lacking in this region.

CONCLUSIONS

This study highlights the need to re-assess the distribution of rocks referred to the Ordovician Oakdale Formation and other conglomerate-olistostromal units attributed to the Macquarie Arc. According to our new interpretation, no autochthonous strata of Ordovician age are recognised in the belt extending from Cumnock to Ponto, west of the Catombal Range. Rocks previously mapped as Oakdale Formation surrounding the abandoned Gunners Dam gold mine are now regarded as a conglomeratic phase of the Kabadah Formation, restricted in age to the Early Silurian. Evidence for the presence of Late Ordovician deep water sediments exposed on the ridge west of Gunners Dam mine (earlier assigned to the Silurian Kabadah Formation, and more recently recognised by Percival and Glen (2007) as a distinctly older unit, the Gunners Dam beds) has been significantly enhanced and confirmed with documentation of a graptolite fauna in siltstones and spiculites, together with conodonts and graptolites in associated cherts. However, these rocks are demonstrably not in place, and (together with a limestone clast of Late Ordovician age) were redeposited into the Silurian sediments. Sandstones and limestones – both abundantly fossiliferous with Late Ordovician faunas – from Narrawa in the Arthurville area along strike to the north, are similarly interpreted as allochthonous blocks emplaced in strata of probable Silurian age. Discrete limestone lenses of Late Ordovician age, previously mapped as an unnamed member within the Sourges Shale at Cumnock, are also here reinterpreted as large allochthonous blocks redeposited in Early Silurian time. Redeposition of Late Ordovician shelfal limestone into trough sediments continued locally (Eurimbla area) into the Late Silurian, while in the Hill End Trough to the east of Wellington, Talent and Mawson (1999) documented an extended history of such events. The presence of allochthonous Ordovician clasts and blocks redeposited into Silurian strata is now widely recognised in central western NSW, and is a significant aspect of the geological history of the Lachlan Orogen.

SYSTEMATIC PALAEONTOLOGY
[I.G. Percival]

Type material (designated MMF), comprising specimens described and illustrated or listed herein, is curated in the palaeontological collections of the Geological Survey of New South Wales held at Londonderry in western Sydney. For brevity, authorship of taxonomic hierarchy above genus level is not cited in the References; these bibliographic sources are listed for brachiopods in the revised (2nd edition) Treatise of Invertebrate Paleontology, Part H: Brachiopoda Volume 3 (Williams et al. 2000), and for graptoloids in the revised (2nd edition) Treatise of Invertebrate Paleontology, Part V (Bulman 1970).

Phylum Brachiopoda Duméril, 1806
Subphylum Rhynchonelliformea Williams, Carlson, Brunton, Holmer and Popov, 1996
Class Strophomenata Williams, Carlson, Brunton, Holmer and Popov, 1996
Order Billingsellida Schuchert, 1893
Superfamily Polytoechioidea Öpik, 1934
Family Tritoechiidae Ulrich and Cooper, 1936

***Narrawaella* gen. nov.**
Type species (by monotypy): *Narrawaella wellingtonense* gen. et sp. nov.

Etymology

In reference to the property Narrawa on which is the type locality lies (gender of name is feminine);

Diagnosis

Planoconvex to ventribiconvex tritoechiid with dorsal sulcus, simple ridge-like cardinal process and complete chilidium; dental plates recessive and merging with delthyrial cavity walls.

Remarks

Narrawaella is assigned to the Tritoechiidae (as revised by Popov et al. 2001) on the basis of possessing a convex deltidial cover, complete chilidium, and a pronounced saccate mantle canal system in the ventral valve, and absence of an anteriorly-elevated ventral muscle platform. Of presumed late Katian age, it is perhaps the youngest representative of this group of billingsellide brachiopods. The preservation of *Narrawaella* is imperfect, as moulds and casts in the medium-coarse grained sandstone matrix do not satisfactorily reproduce fine-scale morphological details. Thus it cannot be confirmed from available material whether a small foramen is present at the apex of the deltidial cover, nor is the precise pattern of mantle canals in the dorsal valve known. Nonetheless, sufficient information is available to readily distinguish *Narrawaella* from other tritoechiids, and to confirm the new genus as an important representative of this group (in fact the first known) from the Ordovician of eastern Australia.

In its plexus of morphological characters, *Narrawaella* has some features reminiscent of the much older (Middle Cambrian to Tremadocian) *Billingsella*, including general shell shape and profile, possession of a tongue-like callus extending anteriorly to support the diductors in the ventral valve, and a similar pattern of ventral valve mantle canals. These general similarities support the argument advanced by Popov et al. (2001) for reassigning the redefined Tritoechiidae from the suborder Clitambonitidina to the suborder Billingsellidina. Although *Narrawaella* is presently known only from an allochthonous deposit (and therefore its age is open to interpretation), lingulate brachiopods and trilobites in closely associated strata provide adequate justification of a Late Ordovician age. Hence it is unlikely that *Narrawaella* is very closely related to *Billingsella*, from which it differs most noticeably in lacking divergent dental plates supporting the teeth. *Narrawaella* also has a shorter ventral interarea, and different ribbing (unequally parvicostellate rather than multicostellate) compared to *Billingsella*.

Narrawaella is readily distinguished from other genera included by Popov et al. (2001) in their redefined Tritoechiidae. In having a planoconvex to ventribiconvex profile with a dorsal sulcus, it differs from *Acanthotoechia* (concavoconvex), *Admixtella* (planoconvex, with dorsal fold and ventral sulcus), *Asymphylotoechia* (biconvex, with dorsal fold and ventral sulcus), *Eremotoechia* (dorsibiconvex), *Platytoechia* (convexiplanar to convexoconcave), and *Protambonites* (dorsibiconvex to resupinate). The simple ridge-like cardinal process of *Narrawaella* is quite unlike the trilobed cardinal process of *Eremotoechia* and *Peritritoechia*, or the swollen cardinal process of many species of *Tritoechia*. *Narrawaella* displays a complete chilidium, rather than the chilidial plates of *Eremotoechia*, *Pomatotrema* and most species of *Tritoechia*. *Korinevskia* Popov et al., 2001 shares several attributes with *Narrawaella*, including a simple cardinal process, complete chilidium, and a fine ridge bisecting the posterior part of the ventral muscle field; *Korinevskia* is, however, convexiplanar, has more prominent dental plates resembling those of *Billingsella*, and the *vascula media* in the ventral valve are subparallel rather than divergent as in *Narrawaella*. Of tritoechiids not mentioned previously, *Martellia* is similar to *Narrawaella* in profile, cardinal process, chilidium, and possessing a strong median septum in the dorsal valve, but differs in having a pronounced median ridge in the ventral valve extending forward of the muscle field (not present in *Narrawaella*).

***Narrawaella wellingtonense* gen. et sp. nov.**
Fig. 6A-T

Diagnosis

As for genus.

Etymology

In reference to the nearby town of Wellington, administrative centre for the district.

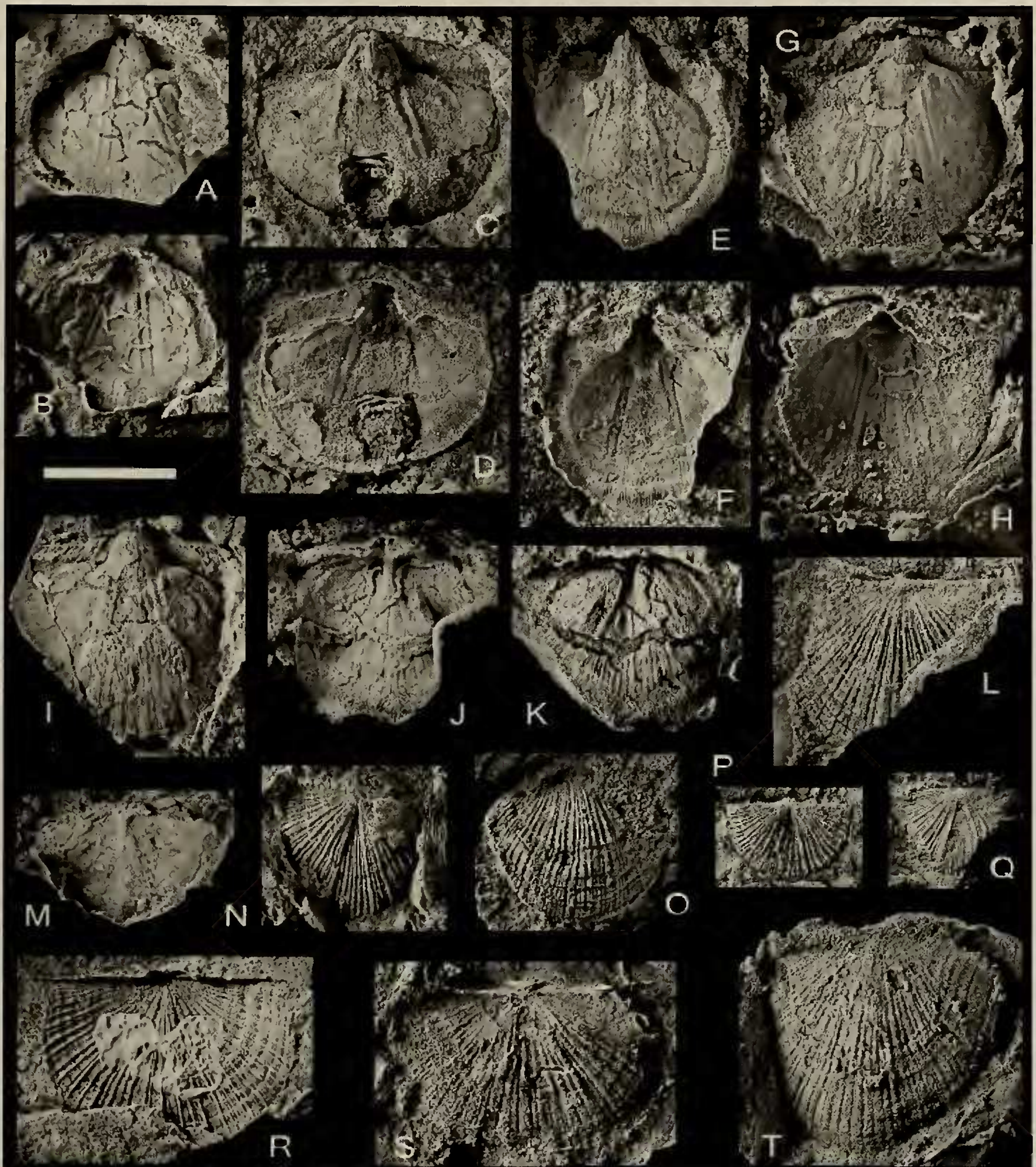

Figure 6. ***Narrawaella wellingtonense*** **gen. et sp. nov; A – B: internal mould and latex cast of ventral valve interior, MMF 45056. C – D: internal mould and latex cast of ventral valve interior, holotype MMF 45053. E – F: internal mould and latex cast of ventral valve interior, MMF 45054. G – H: internal mould and latex cast of ventral valve interior, MMF 45055. I: internal mould of ventral valve interior, MMF 45057. J – K: latex cast and internal mould of dorsal valve interior, MMF 45063. L: latex cast of exterior of dorsal valve, MMF 45065; M: latex cast of interior of dorsal valve, MMF 45064. N: latex cast of exterior of dorsal valve, MMF 45066. O: latex cast of exterior of ventral valve, MMF 45059. P: latex cast of exterior of juvenile dorsal valve, MMF 45067. Q: exterior of juvenile dorsal valve, MMF 45068. R: external mould of exterior of dorsal valve with some adherent shell material, MMF 45069. S: latex cast of exterior of dorsal valve, MMF 45070. T: latex cast of exterior of ventral valve, MMF 45060. Scale bar below B represents 10 mm (magnification x2). All specimens from allochthonous sandstone blocks on Narrawa property, northwest of Wellington.**

Material

Six internal moulds and four external moulds of ventral valves; two internal moulds and eight external moulds of dorsal valves; all shells disarticulated. Holotype is ventral valve MMF 45053; paratypes include ventral valves MMF 45054 – MMF 45062, and dorsal valves MMF 45063 – 45070 (MMF 45058, 45061 and 45062a-b are unfigured).

Type locality

Type (and currently, the only known) locality is low outcrop in paddock, approximately 1.5 km north-north-east of Narrawa homestead, off the Ponto – Arthurville Road about 16 km west of Wellington; GR 669255 6402762 (GDA).

Description

Shell planoconvex to slightly ventribiconvex, with maximum thickness near posterior extremity; outline transversely subquadrate to subquadrate with maximum width generally at, or occasionally immediately anterior to, long straight hingeline; lateral and anterior margins broadly curved; ventral valve with broad median fold of low to moderate convexity and slightly flattened lateral flanks; dorsal valve bearing shallow median sulcus that expands anteriorly. Shell small to moderate in size, ranging in length from 12 to nearly 17 mm, and in width from 15 to about 21 mm (estimated) in largest specimens; length to width ratio 0.85-0.98 (ventral valves), dorsal valves considerably more variable from 0.53 (juveniles) to 0.89 (fully grown). Ventral valve interarea apsacline, of short to moderate length, triangular on each side of a wide delthyrium partly covered posteriorly by a convex cover e.g. Fig. 6D, H (whether deltidium or pseudodeltidium cannot be determined in the available material); dorsal valve interarea catacline to anacline with prominent chilidium (Fig. 6S). Ornament unequally parvicostellate, with 1-2 minor ribs separating rounded major ribs, with very fine concentric filae observed on one specimen (mostly obscured by preservation in medium-coarse grained sandstone), and infrequent concentric growth discontinuities developed anteriorly on larger specimens. Shell material thin; apparently impunctate, but available material is insufficient for more detailed study.

Ventral interior: large, narrowly triangular teeth supported by short convex plates forming walls of delthyrial cavity and extending to valve floor, posteriorly enclosing a moderately deeply excavated muscle field that is supported anteriorly on a very low sessile spondylium extending to approximately one-fifth valve length (Fig. 6G, H); diductor scars entirely enclose narrow median pair of adductor scars that are confined to delthyrial cavity and may be separated by delicate median ridge (Fig. 6A, C), although this is replaced in other specimens by a fine linear cleft (Fig. 6E, G). Mantle canals of saccate type with prominent divergent *vascula media* that extend to four-fifths valve length before branching into fine network of canals (*vascula terminalia*) that occupy the peripheral zone of valve, reaching nearly to the lateral extremities (Fig. 6F); *vascula genitalia* indistinct.

Dorsal interior (Fig. 6J): chilidium is entire, convex, and covers posterior of single thin ridge-like cardinal process supported on a prominent notothyrial platform that merges laterally with short, widely divergent socket ridges; notothyrial platform is slightly undercut anteriorly on either side of a stout low median septum extending to about one-third valve length where it seems to bifurcate in one specimen (Fig. 6M). Muscle scars and mantle canals indistinct, the latter possibly digitate on one specimen (Fig. 6K).

Dimensions (note: for incomplete specimens, full dimensions have been estimated where possible by doubling the measurement of the more complete half)

Holotype MMF 45053 ventral valve: length 15.0 mm, width 17.7 mm; paratypes MMF 45054 ventral valve: length 16.7 mm, estimated width 17 mm; MMF 45055 ventral valve: length 16.0 mm, estimated width 17 mm; MMF 45056 ventral valve: length 13.1 mm, estimated width 15 mm; MMF 45057 ventral valve: length 16.5 mm, estimated width 19.5 mm; MMF 45059 ventral valve: length 11.5+ mm, estimated width 14 mm; MMF 45060 ventral valve: length 16.4+ mm, estimated width 21 mm; MMF 45063 dorsal valve: length 13.1 mm, estimated width 16+ mm; MMF 45064 dorsal valve: length 9.4+ mm, width 15.4+ mm; MMF 45065 dorsal valve: length 15.3+ mm, width 10.5+ mm; MMF 45066 dorsal valve: length 9.8 mm, estimated width 11 mm; MMF 45067 juvenile dorsal valve: length 6.1 mm, width 11.3 mm; MMF 45068 juvenile dorsal valve: length 6.8 mm, estimated width 9 mm; MMF 45069 dorsal valve: length 11.8 mm, width 17.1 mm; MMF 45070 dorsal valve: length 12.5 mm, estimated width 19 mm.

Discussion

Popov et al. (2001) observed that there is considerable variation present within the current concept of *Tritoechia.* These authors described a new species, *T. crassa* from the early Darriwilian Uzunbulak Formation of south Kazakhstan (see also Nikitina et al. 2006) that has a simple cardinal process, complete chilidium, dorsal sulcus, unequally parvicostellate ornament, and a similar ventral muscle field to that of *Narrawaella*. A highly ventribiconvex profile distinguishes *T. crassa* from *N. wellingtonense*, but it is feasible that it and the Kazakhstan species are quite closely related.

Distribution

Late Eastonian (Ea3-4), equivalent to late Katian; presently monotypic and known only from allochthonous sandstone redeposited into Silurian sediments, west of Wellington in central NSW.

Phylum Hemichordata Bateson, 1885, emend. Fowler, 1892
Class Graptolithina Bronn, 1846
Order Dendroidea Nicholson, 1872
Family Dendrograptidae Roemer in Frech, 1897
***Dendrograptus* J. Hall, 1858**

***Dendrograptus* sp.**
Fig. 3A, C

Material

Two specimens, MMF 45087 and MMF 45089, from an allochthonous block in the Gunners Dam sequence at Locality 1, GR 665950 6380820 (GDA), west of abandoned Gunners Dam mine, southwest of Wellington, NSW.

Description

Rhabdosome laterally flattened in both cases; the larger specimen (MMF 45087, Fig. 3A) retains some relief above the bedding plane and is approximately 7.4 cm across and 4.7 cm high. Stipes radiate from a diffuse node, branching at a constant rate of 5-6 stipes per cm to form a moderately clustered network exhibiting continuous expanding dichotomisation. There is very little variation in stipe thickness (approximately 1.0 mm), except at their slightly thinner terminations. No autothecae or bithecae visible, nor are any dissepiments seen.

The second specimen (MMF 45089, Fig. 3C) is better preserved but considerably smaller, only 2.0 cm across by 2.8 cm high. Branching is relatively open and apparently more ordered than in the other specimen, with new stipes arising on average every 2 mm (about the same as in MMF 45087), but they are comparatively thinner (0.5-0.6 mm). Autothecae not confirmed; dissepiments lacking.

Remarks

Only one species is believed to be present, the differences in stipe thickness being attributable to preservational vagaries (the larger specimen occurring in spiculitic siltstone, the smaller one being preserved in finer grained siltstone).

Species of *Dendrograptus* have previously been described in NSW from Upper Ordovician black shales (Bendoc Group) at Tomingley north of Peak Hill (Sherrard 1956), from the Lower Silurian (Llandovery) Glendalough Formation of the Waugoola Group in the Four Mile Creek area west of Cadia (Rickards et al. 2003), and from the late Ludlow upper Black Bog Shale at Yass (Rickards and Wright 1999). An additional undetermined species of Wenlock to Ludlow age was illustrated by Rickards et al. (1995) from the Panuara Formation of the Quarry Creek area west of Mount Canobolas. The branching pattern of none of these previously documented species closely resembles that of the Gunners Dam specimens, but the latter are not sufficiently well preserved to establish as new species.

An additional dendroid specimen (MMF 45088, Fig. 3B) from the same locality is tentatively attributed to *Dictyonema*, on the basis of having parallel stipes (12-13 per cm) connected by sparse dissepiments. Although too poorly preserved to describe, it is documented here by illustration.

NOTES ON ASSOCIATED DICRANOGRAPTID AND DIPLOGRAPTID GRAPTOLITES

Graptolites have now been found at two localities in the Gunners Dam sequence. None is sufficiently well-preserved to be described and confidently assigned to a species. Nonetheless their occurrence is crucial for confirming the Late Ordovician age of the allochthonous siltstones in this belt to the west of the Gunners Dam mine, so they will be briefly discussed here.

The most significant is a specimen of *Dicellograptus* (Fig. 4N), which shows broad similarities to several species that typically range from mid to late Eastonian into the early and mid Bolindian (VandenBerg and Cooper 1992). In the absence of details of thecae it is pointless to speculate about its identity. Associated graptoloids found at locality 1 include *Dendrograptus* sp. (described above), and an indeterminate climacograptid (Fig. 3C, and another example Fig. 4A). Sections cut of chert from this locality revealed proximal ends of four graptolites, two of which (Fig. 5B, D) display a pair of basal spines, similar to those exhibited by *Diplacanthograptus spiniferus* (mid to late Eastonian) or *Appendispinograptus supernus* (of Bolindian age). The available material, although too poor to confirm an identification, lends support to the general Late Ordovician age of the fauna.

Graptolites from locality 2 in the Gunners Dam sequence (Fig. 4B – L) are more prolific but less diverse. The majority appear to be referable to *Climacograptus*, perhaps here represented by more than one species. Better preserved examples (e.g. Fig. 4F) are 15 mm in length (including nema), have 12 thecae per cm, with stipes a relatively constant 1 mm in thickness. Other specimens show a gentle taper throughout the length of the stipe (Fig. 4C). No definite age connotations can be ascribed to this fauna, but it is again entirely consistent with a Late Ordovician age.

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